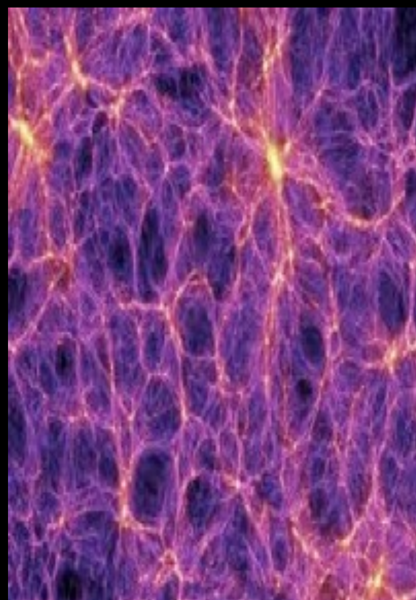
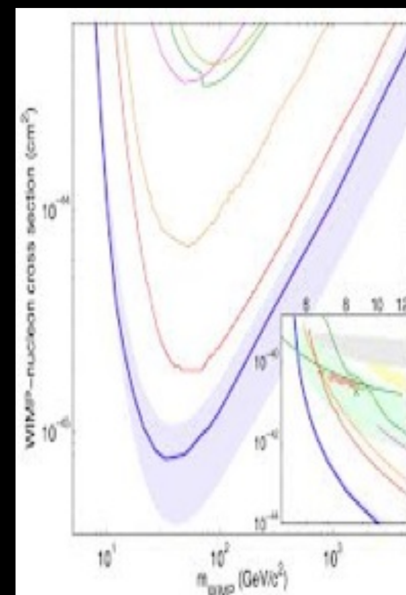
SuperCDMS Low-Mass WIMP Searches





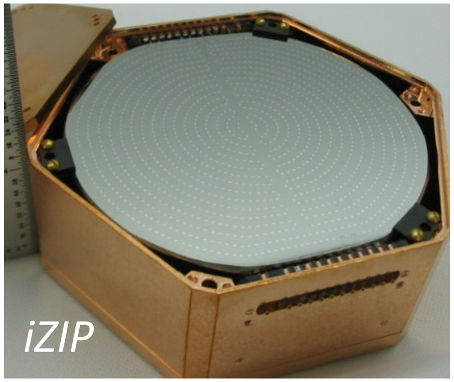
Lauren Hsu

Fermilab Center for Particle Astrophysics

New Perspectives on Dark Matter

Fermilab, April 30, 2014

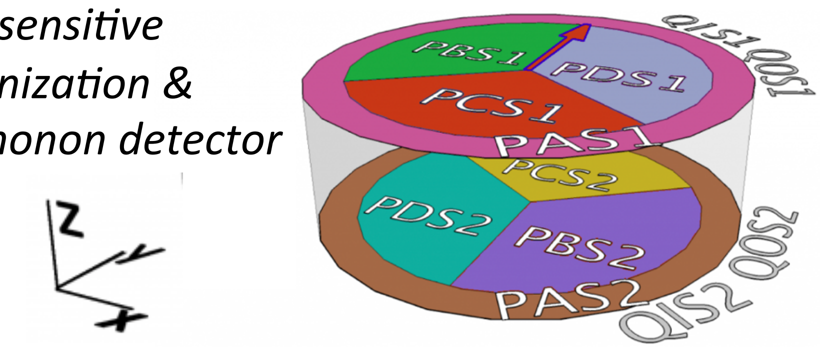
SuperCDMS Soudan Overview

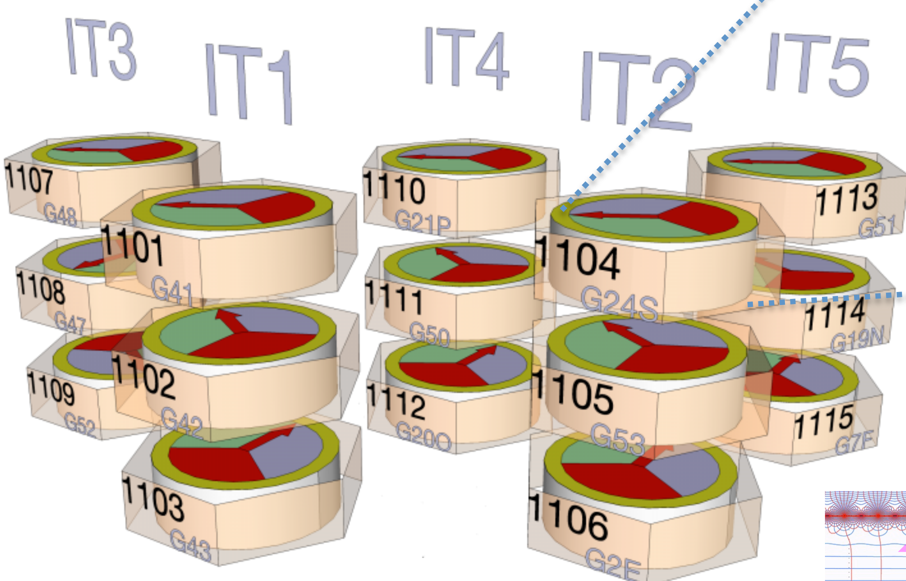


SuperCDMS Soudan

Looking for SI elastic scattering of relic WIMPs off Ge

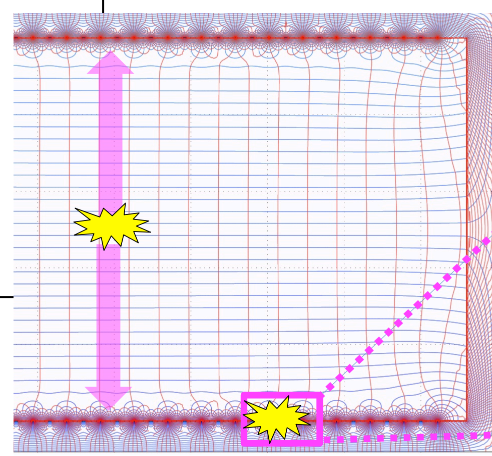
<u>i</u>nterleaved
<u>Z</u>-sensitive
<u>I</u>onization &
<u>P</u>honon detector



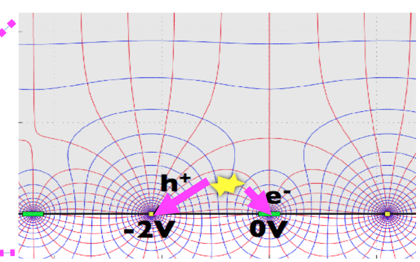


15 Germanium detectors
0.6 kg each
Operational since March of 2012

3-D fiducialization from measurement of z-symmetric ionization or phonon response and outer "guard" channels



APL 103, 164105(2013)

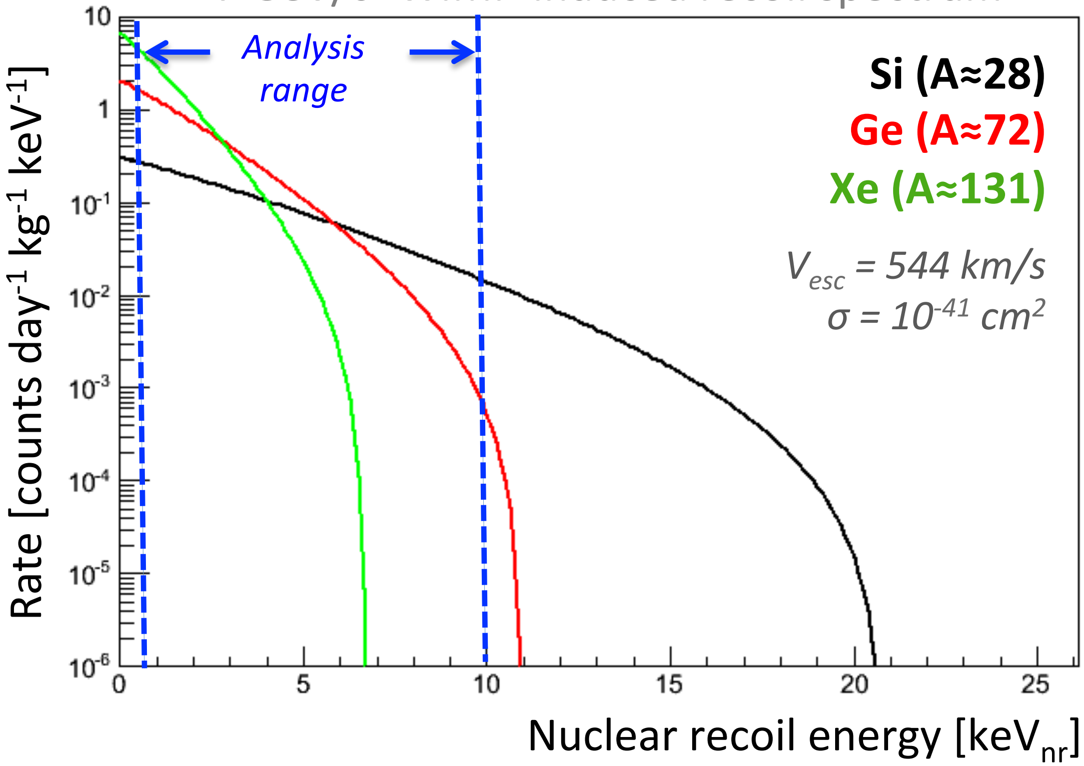


Data taken from Mar 2012 – present; The two analyses presented here use a subset of the full dataset

Optimizing for Low Mass

Experiments with lighter targets and lower thresholds have the advantage when looking for WIMPs with mass < 10 GeV/c^2

7 GeV/c^2 WIMP-induced recoil spectrum



Our strategy:

Ge is a relatively heavy target so go as low in threshold as possible

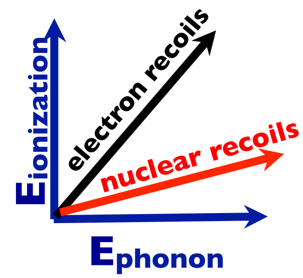
SuperCDMS Low-Mass: minimum recoil energy 1.6 keV$_{nr}$

CDMSlite Run I: minimum recoil energy ~0.8 keV$_{nr}$

We expect background events in the signal region!! Tradeoff is greater sensitivity to low mass WIMPs.

Backgrounds

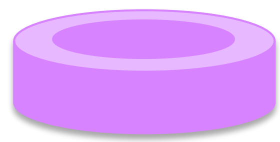
Bulk electron recoils =
Compton background and 1.3 keV activation line



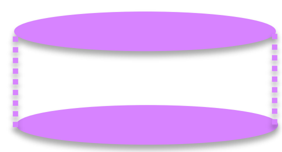
Ionization vs phonon distinguishes NR from bulk ER

sidewall & surface events =
betas and x-rays from ^{210}Pb, ^{210}Bi, recoils from ^{206}Pb, outer radial comptons and ejected electrons from compton scattering

for modeling ^{210}Pb bg in Geant4, see P. Redl's talk



Use division of energy between inner and outer sensors, "radial partition"



Use division of energy between sides 1 and 2, "z-partition"

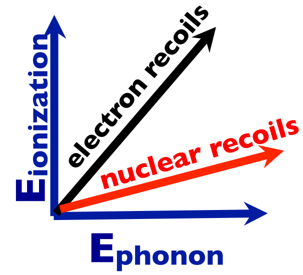
Cosmogenic & radiogenic neutrons

Use active and passive shielding. Simulation determines remaining irreducible rate

Backgrounds

Note: event-by-event yield and z-partition discrimination not possible for CDMSlite

Bulk electron recoils =
Compton background and 1.3 keV activation line



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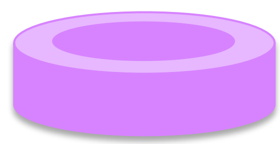

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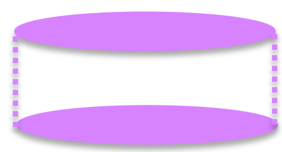

Use division of energy between sides 1 and 2, "z-partition"

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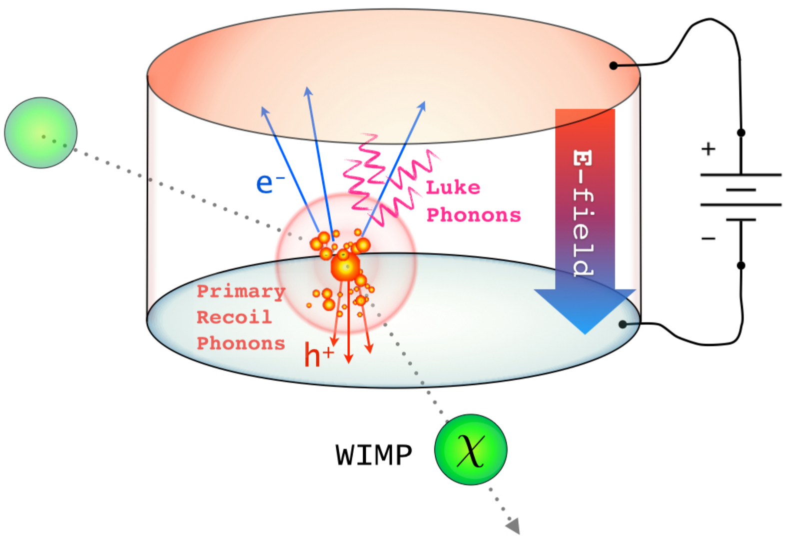
Use active and passive shielding. Simulation determines remaining irreducible rate

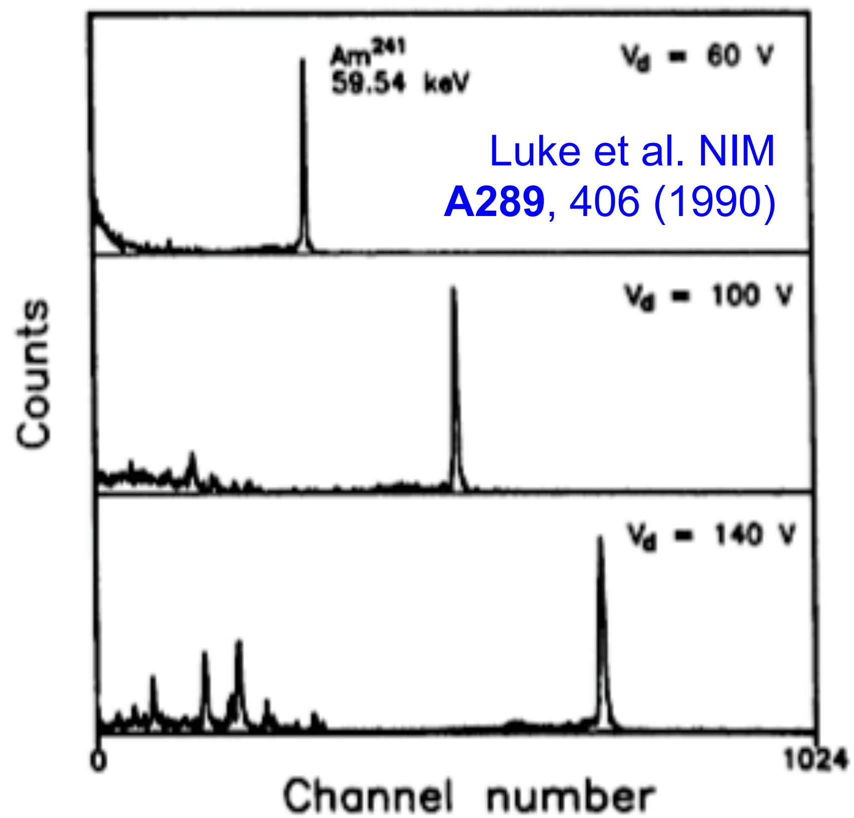
CDMSlite First Results

(Ultra) Low Ionization Threshold Experiment: CDMSlite

Neganov-Luke amplification of phonon response allows operation at very low energy thresholds



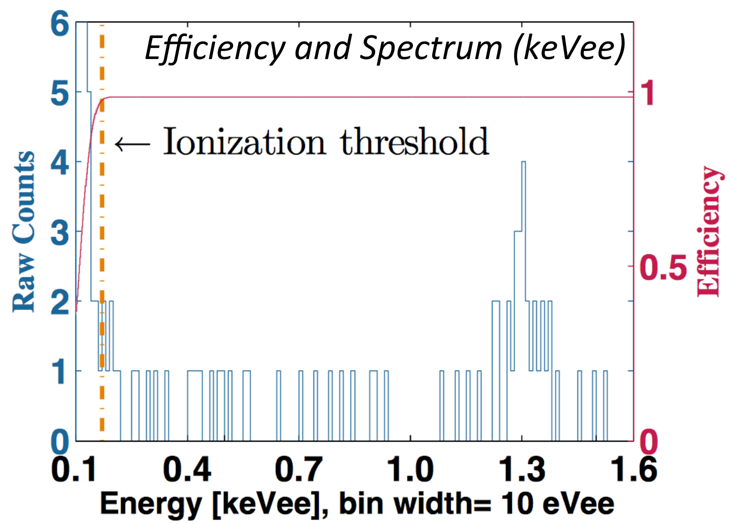
Electrons and holes radiate phonons proportional to V_{bias} as they drift to the electrodes. ➔Apply large V_{bias} to amplify ionization signal

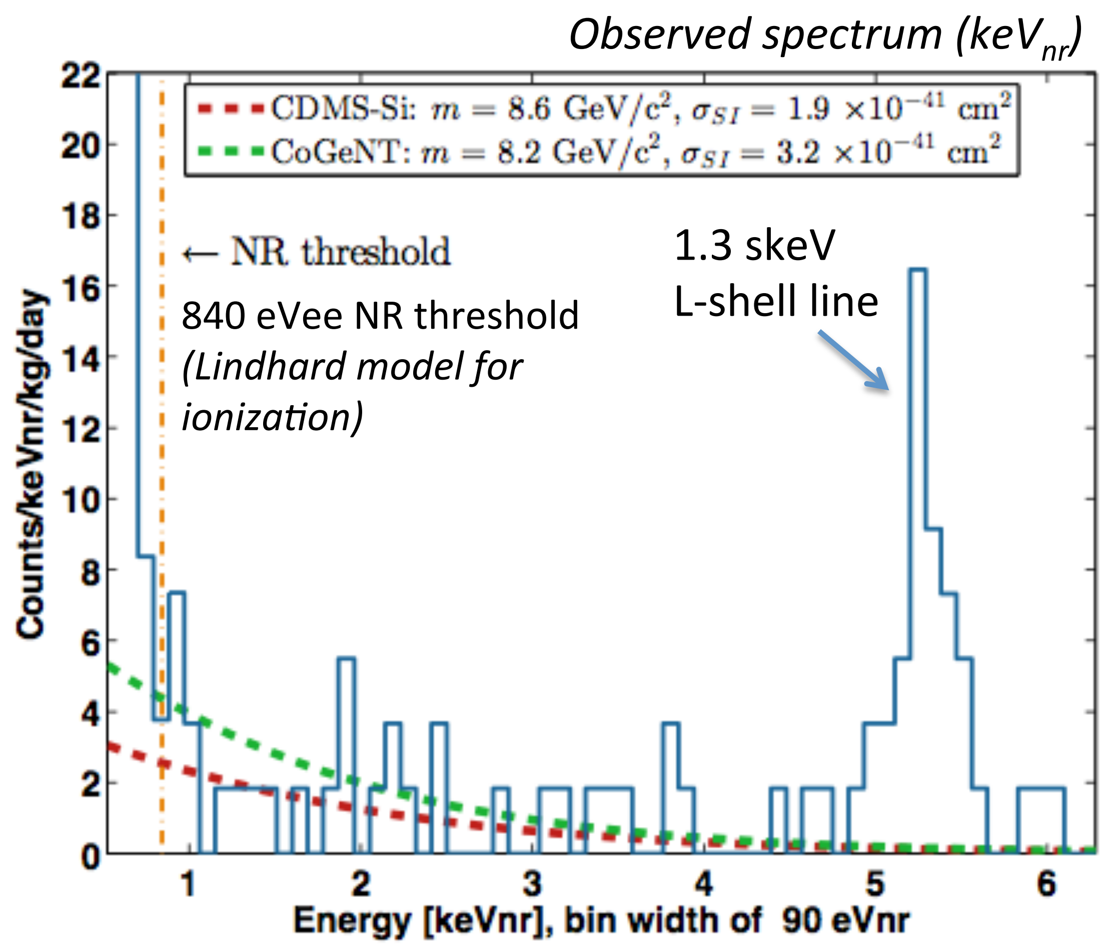


Ionization and phonon measurements are redundant in this mode; trading-off background rejection for lower thresholds

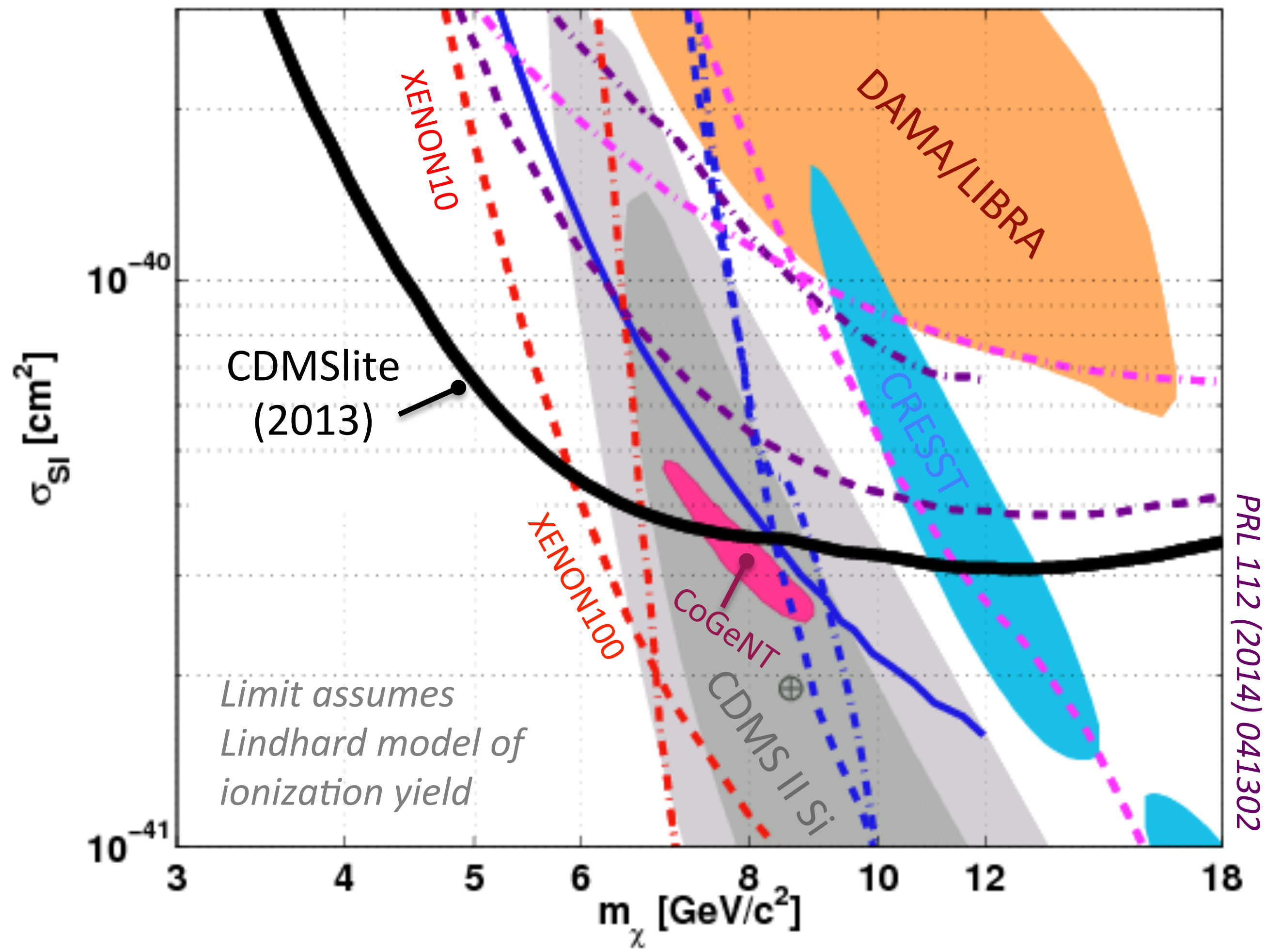
CDMSlite First Analysis in 2013

- One 0.6 iZIP for ~10 live days (~6 kg days), 1-sided read-out
- Open analysis (not blind)
- Minimal cuts to select good data periods, reject noise, single-iZIP scatters and veto anticoincident events
- Achieved threshold 170 eV_{ee} (!)





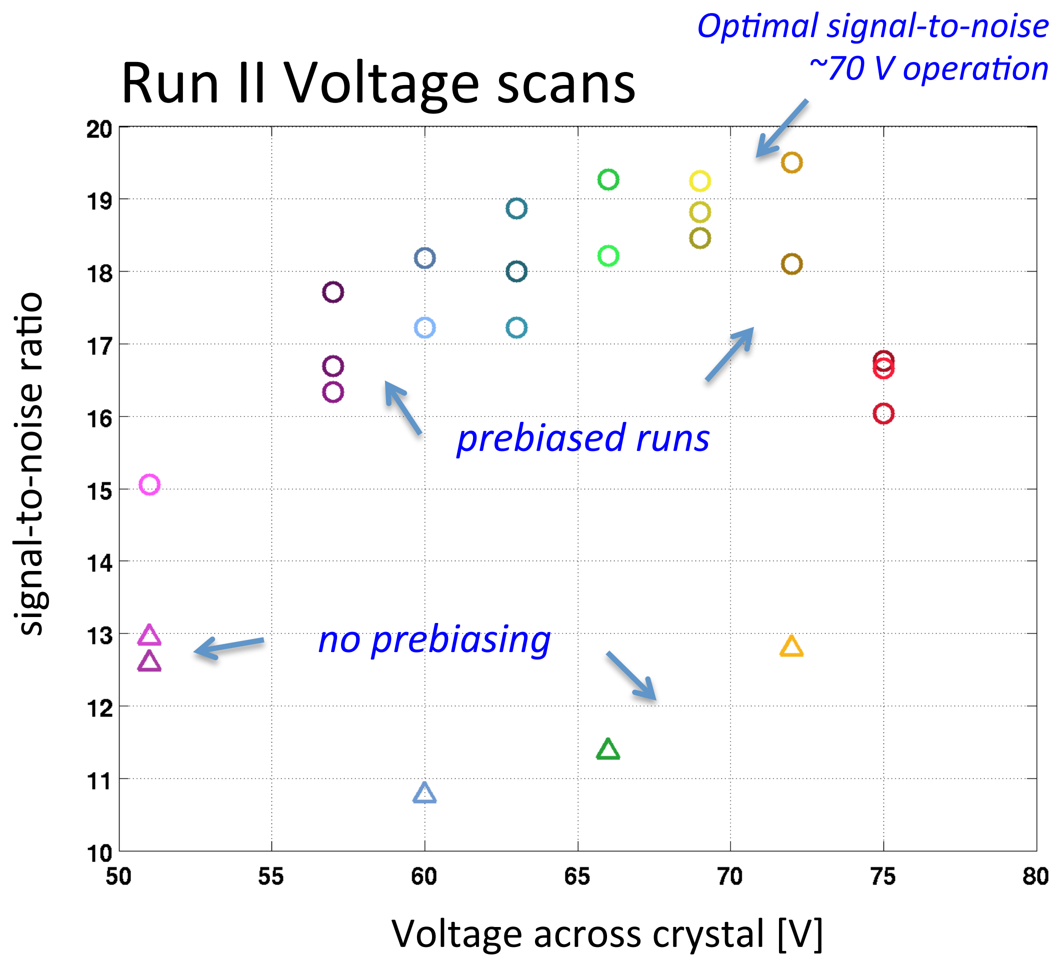
CDMSlite Run I: Exclusion Limits



World-leading limit w/ ~10 day exposure and one detector!

CDMSlite Run II

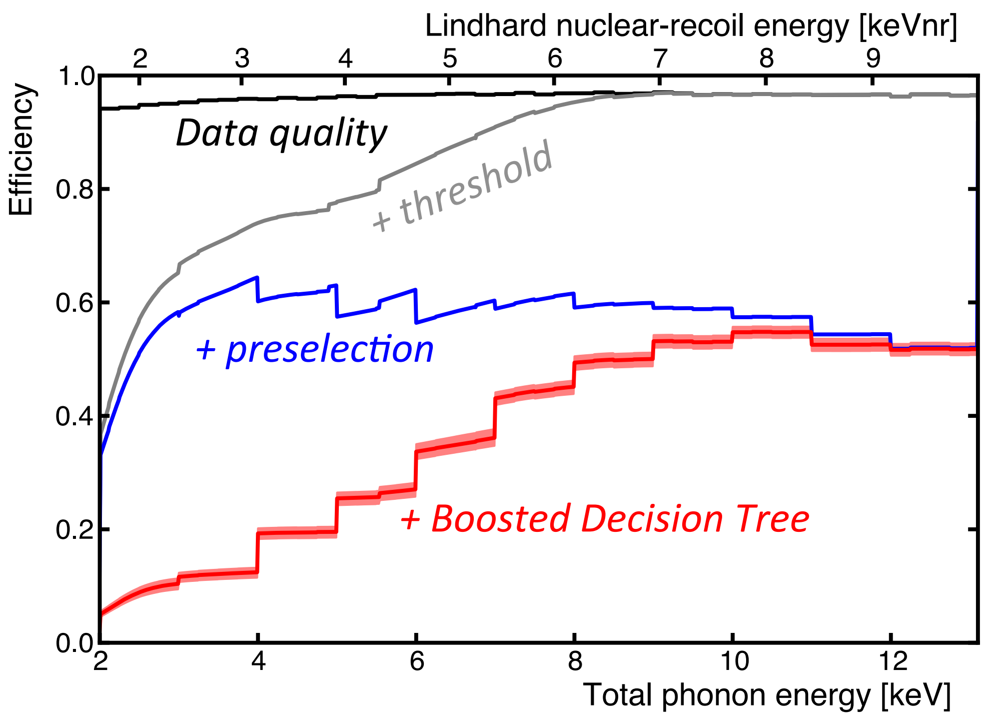
- Ongoing since Jan 2014 with same detector (T5Z2), operating at 70V bias
- Goal: take 6 months of data to better understand backgrounds and attempt subtraction to improve CDMSlite sensitivity; explore use of phonon radial cut to reject some background
- ~50% reduction in noise
- Operating at 70V bias; prebiasing reduces leakage current at start of run and improves livetime



First SuperCDMS WIMP Search
w/
background rejection

Analysis Summary

Dataset: 7 lowest threshold iZIPs w/ data taken from Oct. 2012- June 2013. All singles in analysis energy range blinded during cut tuning, except data following ^{252}Cf calibration. Blinded data totals 577 kg-days. Non-blind data not used for limit calc.



Efficiencies: *measured with neutrons from ^{252}Cf.*
Geant4 used to correct for multiple scattering, yields ~25% correction

Data Quality:

- Reject periods of high/abnormal noise
- Reject atypical operational periods

Trigger and Analysis Threshold:

- Select periods of stable, well-defined trigger threshold
- Analysis thresholds based on time-varying noise baseline

Preselection:

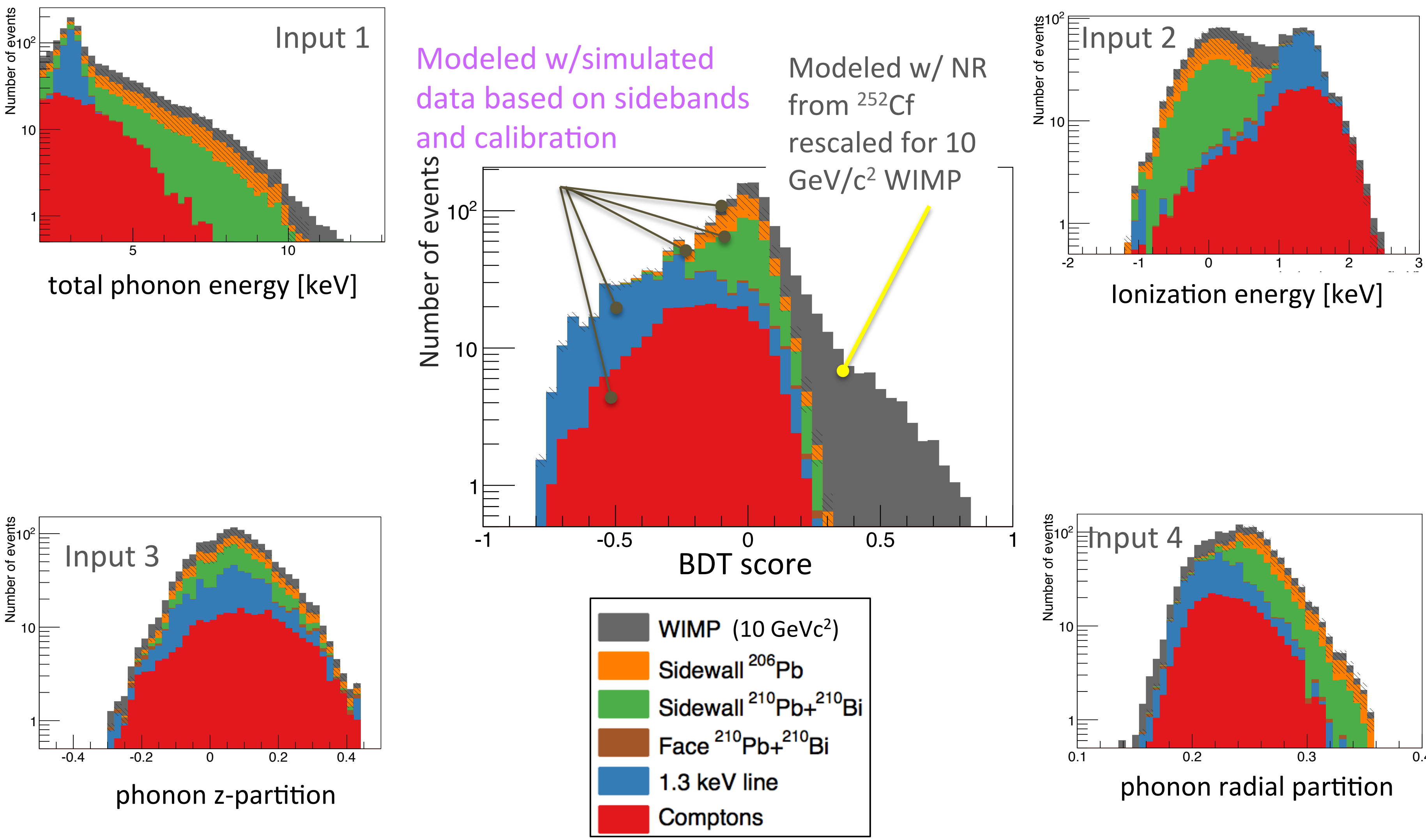
- Single-detector scatter
- Muon veto anticoincident
- ionization fiducial volume
- Ionization energy and phonon partitions consistent w/ NR

Boosted Decision Tree

- "tight" phonon fiducial volume and ionization yield at low energy

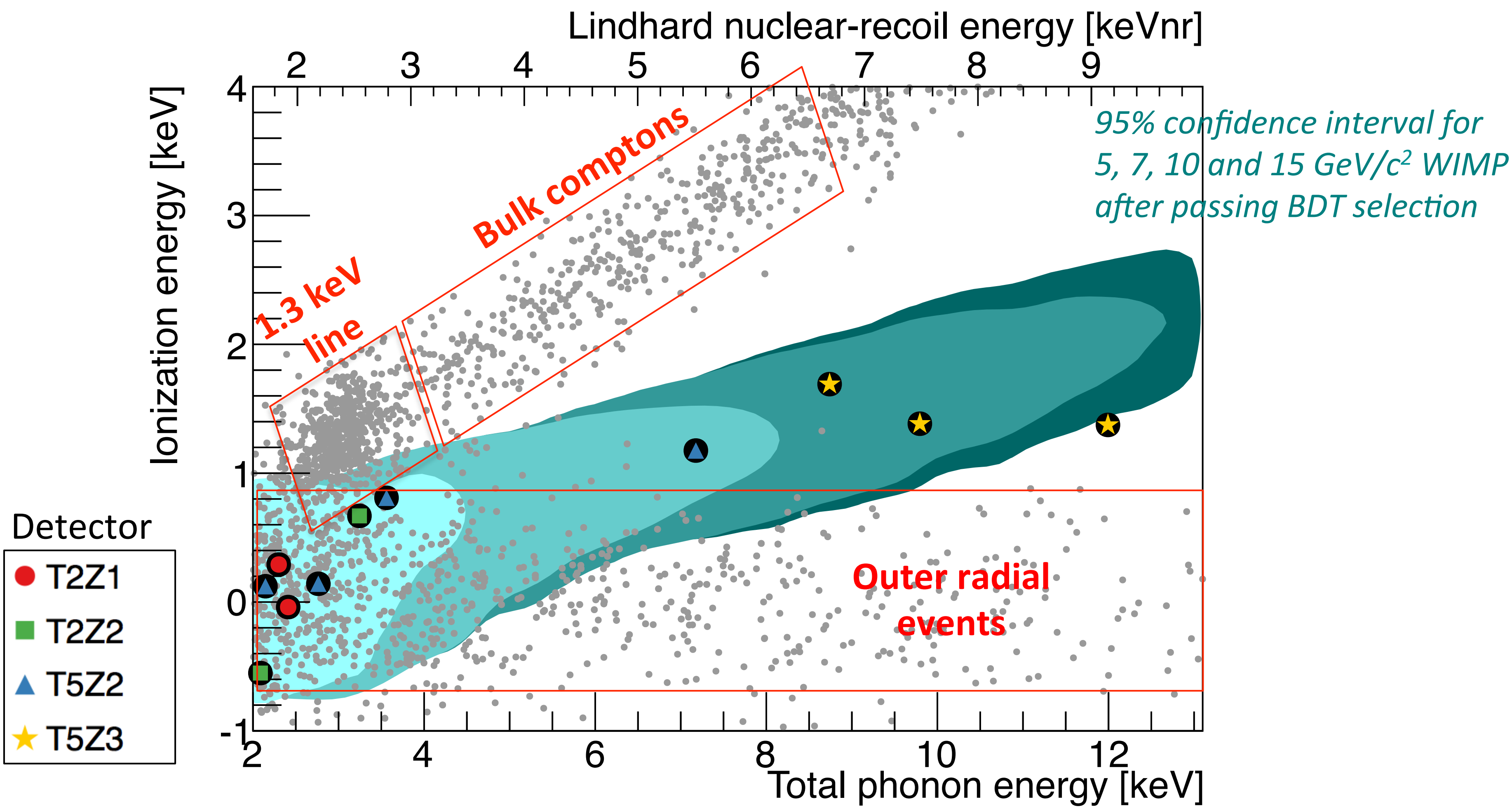
Boosted Decision Tree (BDT)

Discrimination lies in correlations between 4 parameters in partition and energy



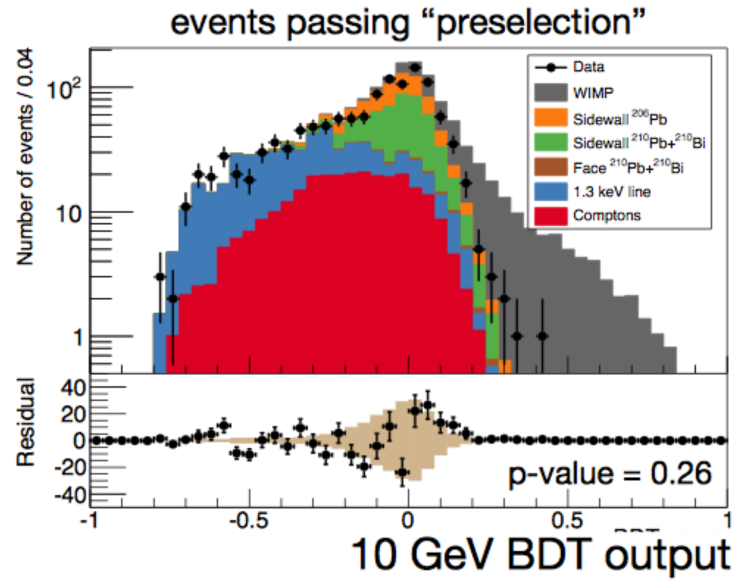
Unblinded Data

Eleven candidates seen, 6.2 +1.1 -0.8 expected



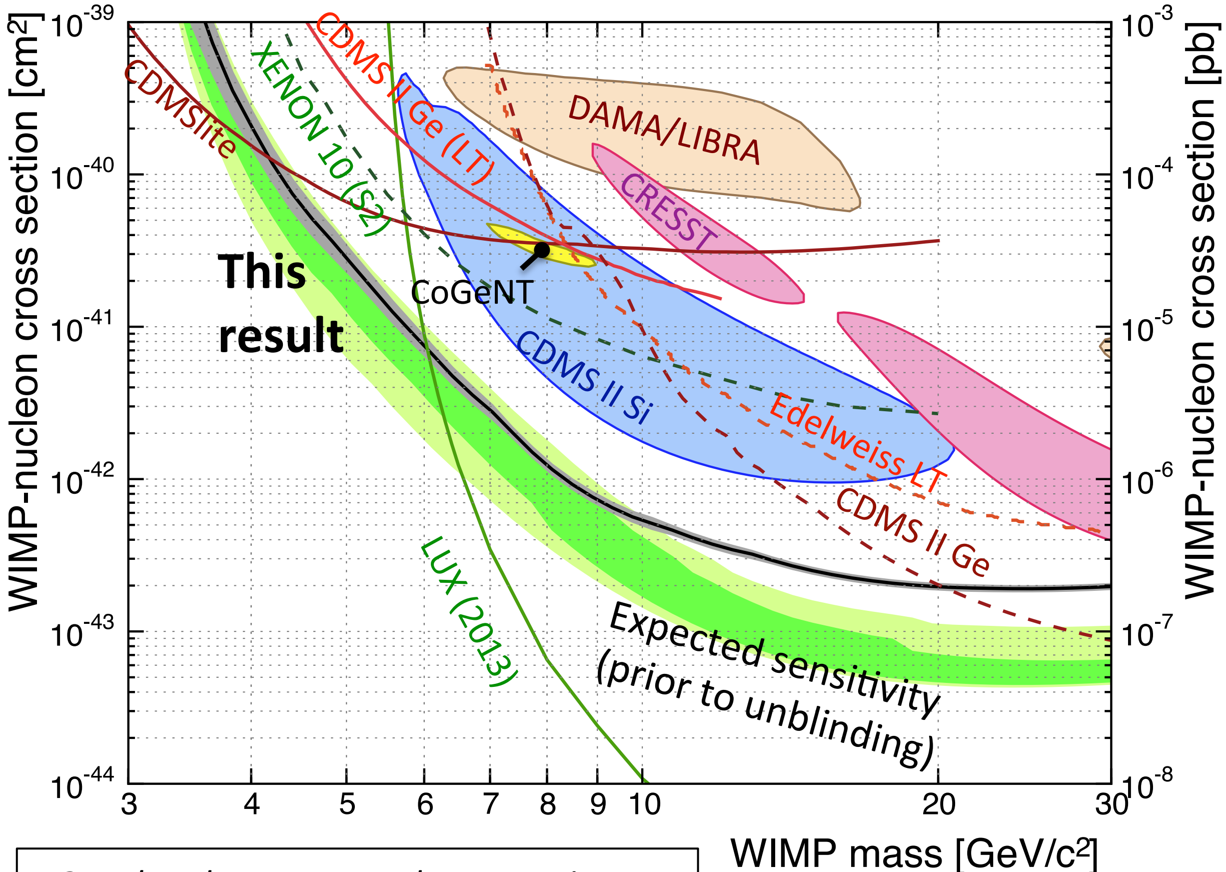
Post-unblinding analysis

- Background consistent with expectations overall and on most individual detectors
- Background model **accurate in full preselection region**
- Shorted ionization guard on T5Z3 may have affected background model performance—*further study ongoing*
- Poisson p-value for T5Z3 is 0.04%, and even lower considering only high event energies



Spin-independent Scattering Constraints

90% C.L. optimal interval upper limit, no background subtraction, treating all observed (eleven) events as WIMP candidates



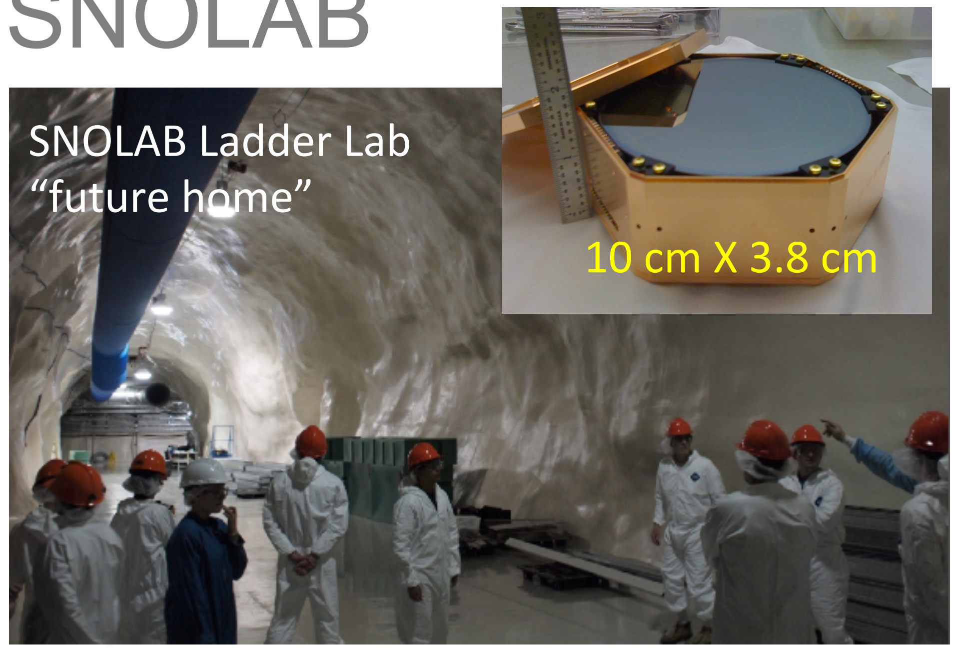
Gray bands: propagated systematic unc. from fiducial volume + nuclear recoil energy scale + trigger efficiency

- CoGeNT strongly disfavored in model-independent scenario
- CDMS II (Si) disfavored under assumption of standard halo model and A^2 coupling
- Competitive constraint for Ge up to 20 GeV/c^2; dedicated HT analysis yet to come
- Disagreement between limit and sensitivity at high WIMP mass mostly due to events on T5Z3.

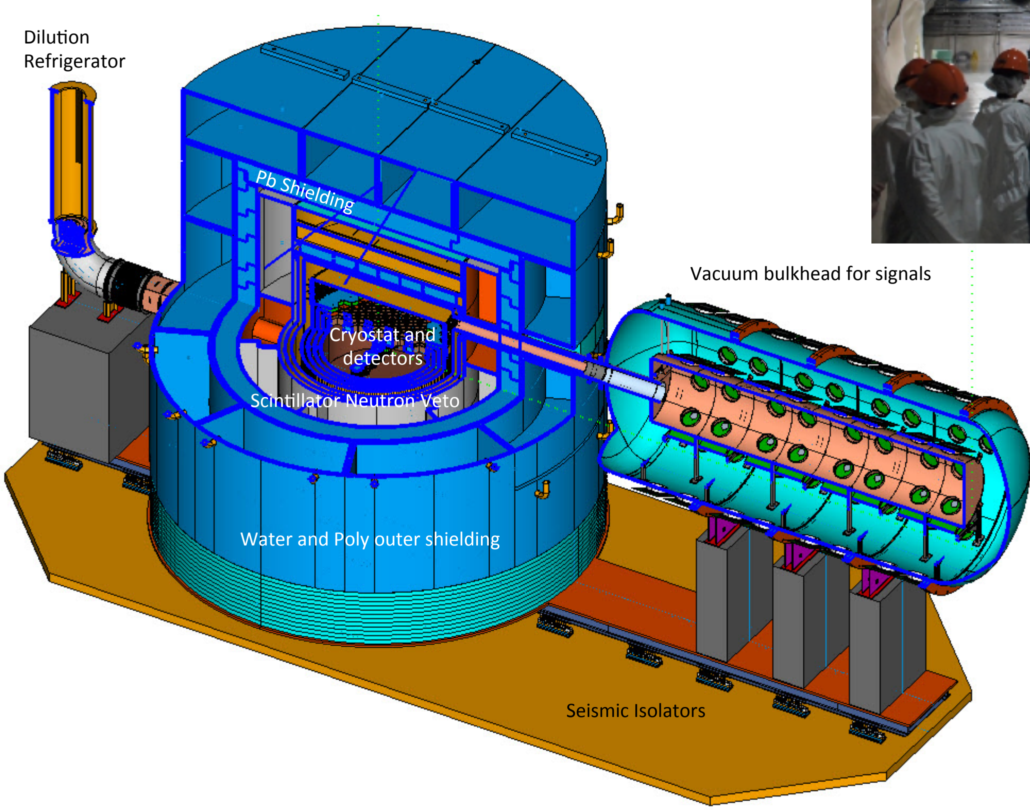
Low Mass WIMP searches
w/
SuperCDMS Generation 2

WIMP Searches w/ SuperCDMS SNOLAB

SNOLAB
MINING FOR KNOWLEDGE
CREUSER POUR TROUVER... L'EXCELLENCE



~100 kg of mixed Ge/Si payload, w/ 5% detectors configured in CDMSlite mode



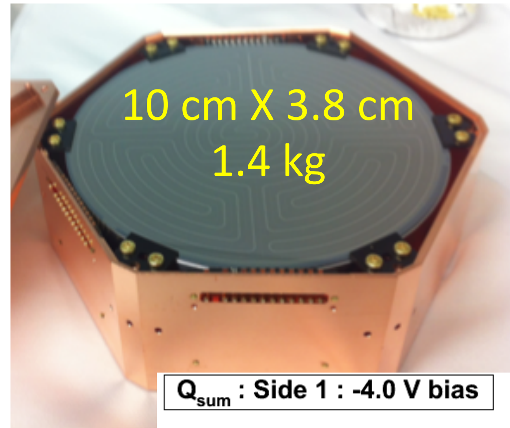
- Locate in North America's deepest underground lab
- Bigger iZIP detectors
- Cleaner shielding, w/ active neutron veto
- Upgraded electronics
- Room to expand to 400 kg

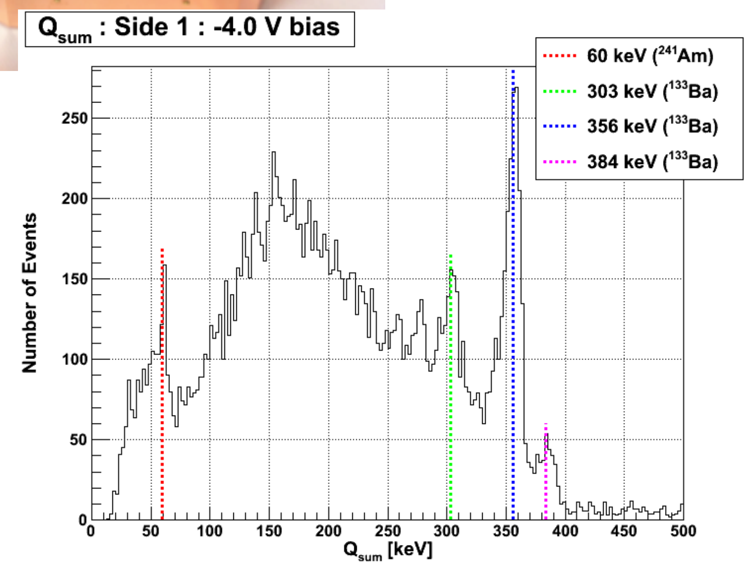
Improvements for Low-Mass Searches

- **Bigger detectors:** reduce surface events, accumulate exposure faster, lower fabrication costs

- **3-4X Better resolution in ionization and phonon channels:** lowers trigger threshold AND improves separation of signal from background

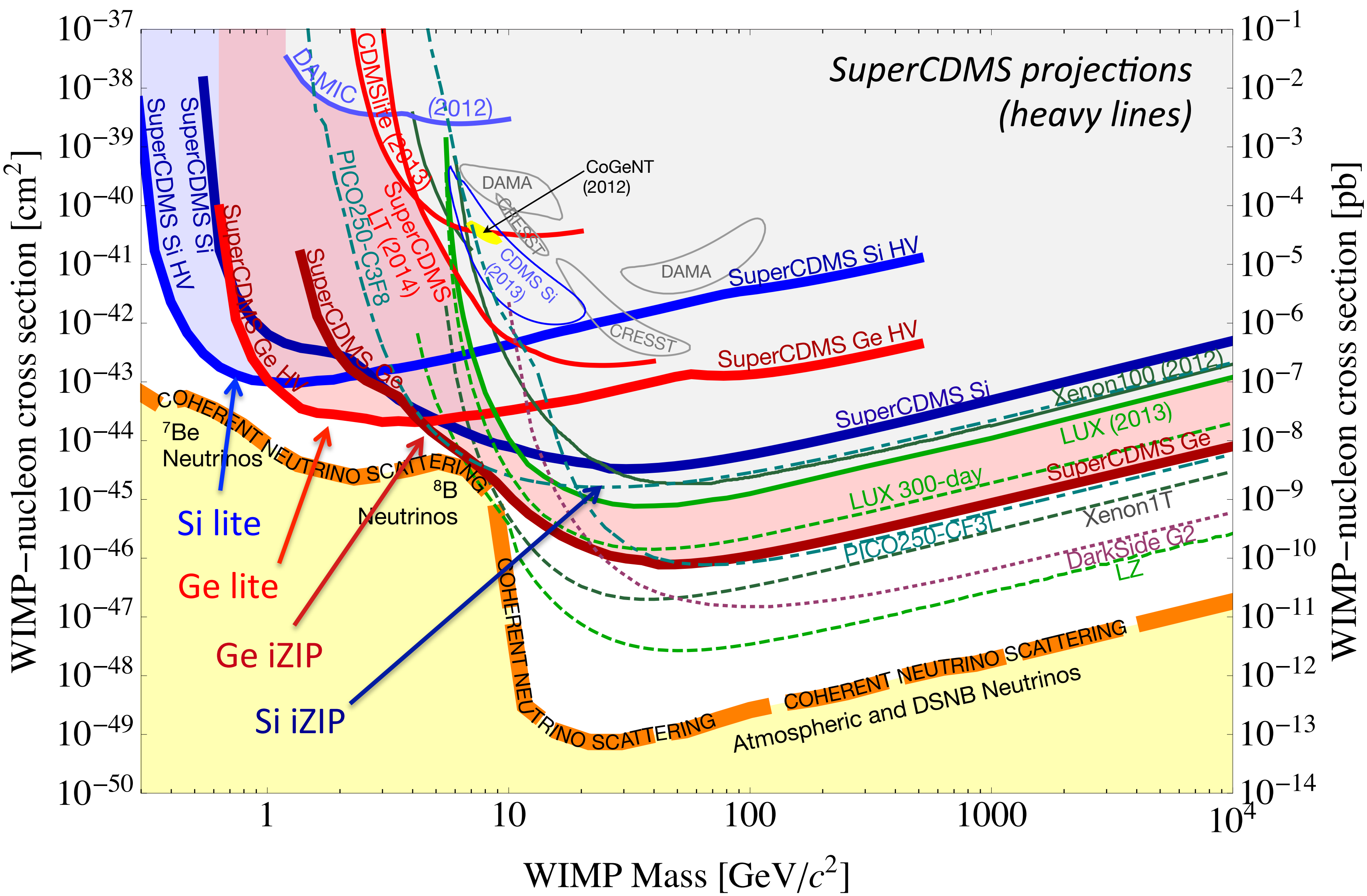
- **> 10X Cleaner:** reduces intrinsic sources of background; applying levels demonstrated by published literature will reduce backgrounds by > 10X





Note: background rejection demonstrated with Soudan detectors already meets requirements for <1 event background for 10 GeV WIMP searches!

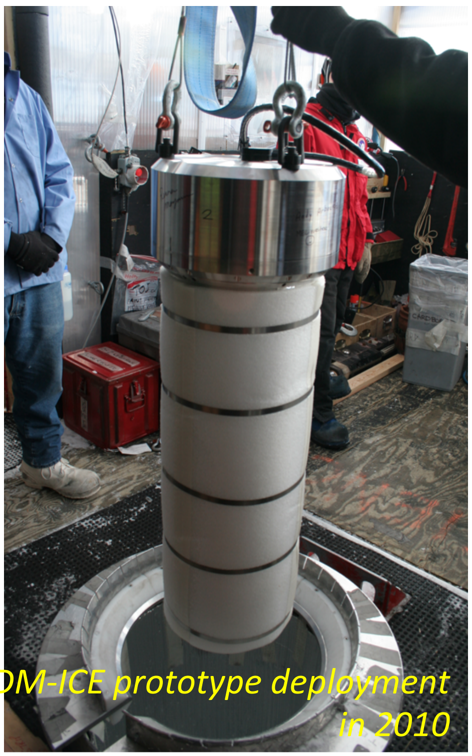
SNOLAB Projections



Brief discussion of DM-Ice

Annual modulation with DM-Ice

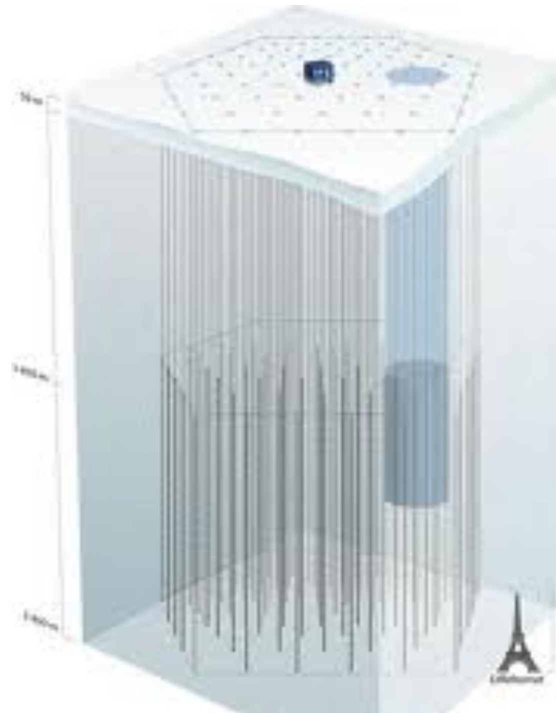
Resolving the DAMA annual modulation puzzle remains a high scientific priority



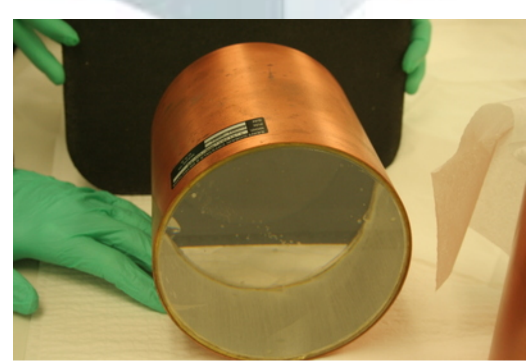
DM-ICE prototype deployment in 2010

DM-ICE

Aims to deploy ~200 kg of NaI crystals on ICECUBE strings, within the ICECUBE detector



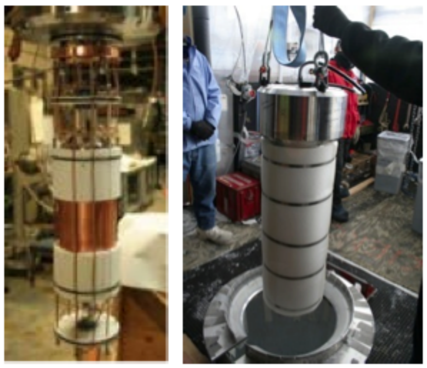
Backgrounds tied to seasonal effects will modulate with a different phase in the Southern Hemisphere



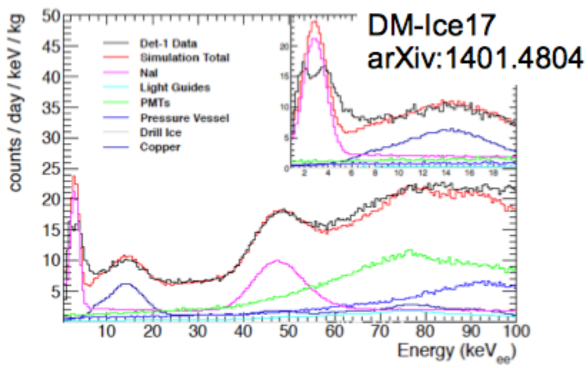
Backgrounds and sensitivity described in: Astropart. Physics 35 (2012), 749-754

DM-Ice Staged Approach

DM-Ice17 *(running now)*

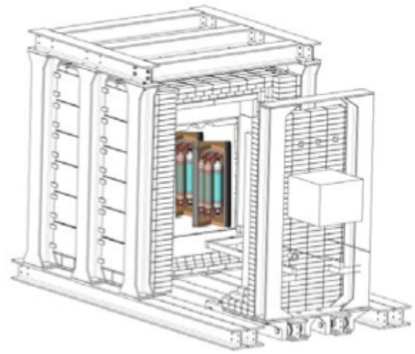


Test Detector at South Pole



17 kg of NaI(Tl) at 2450m depth
in operation since 2011

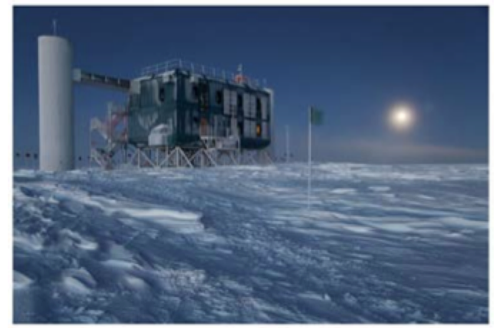
DM-Ice250 North



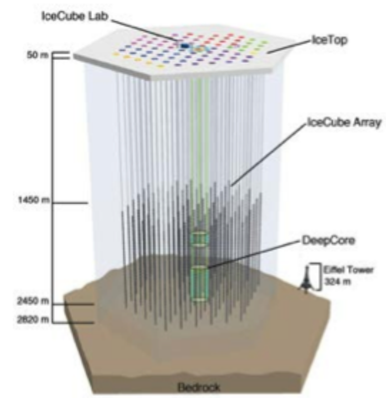
Modulation Search in Northern Hemisphere

portable 250kg NaI(Tl) array
existing shield, ready in 2015/2016

DM-Ice250 South



Modulation Search at South Pole



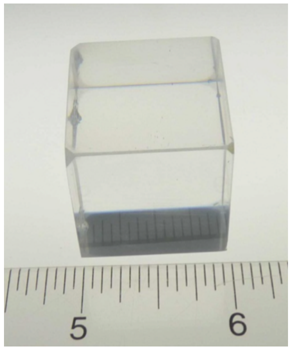
if modulation seen in North and
environmental effects ruled out

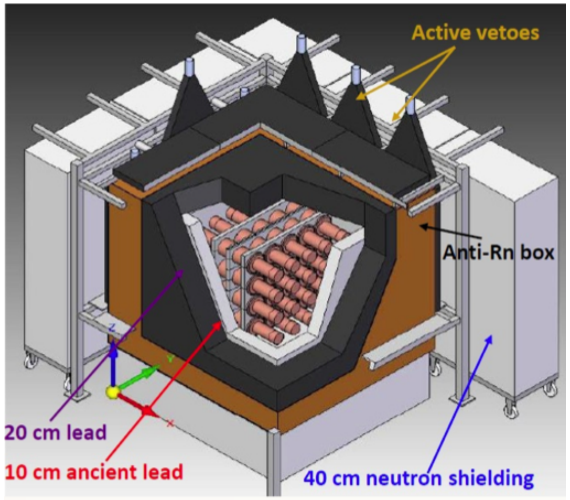
Funds for DM-Ice250 North requested with 2013 G2 competition

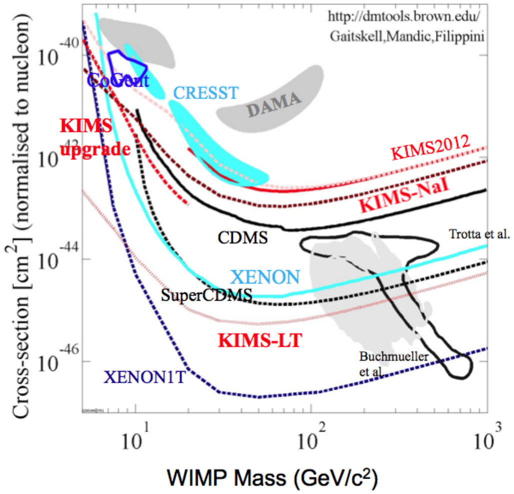
Other searches with NaI (world-wide)

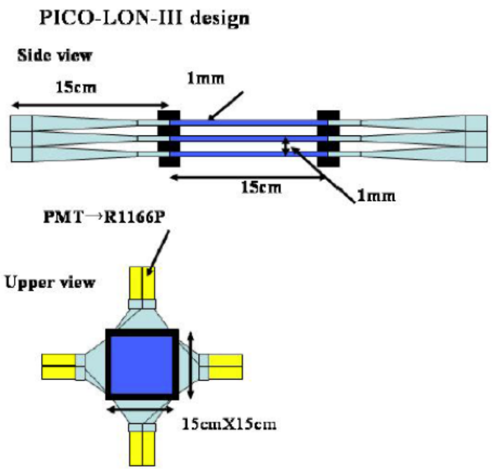
R&D for clean NaI crystals is key; technology was locked up by DAMA for some years, but situation is changing

- SABRE: reducing intrinsic background by order of magnitude or more with ultra-clean crystals; use Borexino CTF as active shield, deploy in Gran Sasso
- ANAIS: similar setup to DAMA, deployed in Canfranc, has funding for 200-kg array, MOU with DM-Ice
- KIMS: running ~100kg CsI array, will upgrade to include NaI crystals in 2015, deployed in Yangyang mine
- KamLAND-PICO: use KamLAND LS detector as active gamma veto, deploy up to 1 ton of NaI crystals









Summary

This past year saw the first results from SuperCDMS Soudan:

Search for Low-Mass WIMPs with voltage-amplification (CDMSlite); see *PRL 112 (2014) 041302 for more*

Search for Low-Mass WIMPs with full background rejection capability of iZIPs; see *arXiv 1402.7137 for more*

CoGeNT interpretation of WIMPs strongly disfavored in model-independent scenario; CDMS II (Si) region disfavored under standard halo model and A^2 coupling

SuperCDMS SNOLAB will have complementary sensitivity in searches for high-mass WIMPs and unprecedented reach in searches for low-mass WIMPs